Use of a clinical event monitor to prevent and detect medication errors

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ABSTRACT

Errors in health care facilities are common and often unrecognized. We have used our clinical event monitor to prevent and detect medication errors by scrutinizing electronic messages sent to it when any medication order is written in our facility. A growing collection of medication safety rules covering dose limit errors, laboratory monitoring, and other topics may be applied to each medication order message to provide an additional layer of protection beyond existing order checks, reminders, and alerts available within our computer-based record system. During a typical day the event monitor receives 4802 messages, of which 4719 pertain to medication orders. We have found the clinical event monitor to be a valuable tool for clinicians and quality management groups charged with improving medication safety.

BACKGROUND

Errors in the health care setting occur often, though they are often unrecognized [1]. In a comprehensive study conducted at a large academic medical center, there were 247 adverse drug events—many of which were preventable—over a 6 month period [2]. There are many methods for reducing errors, including use of checklists, cultural changes, training, and the implementation of automated systems [1].

Among technical means for reducing medication errors are automated practitioner order entry [3], real-time order checks, pharmacy dispensing systems, medication administration systems, and others. A recent report on medical errors by the Institute of Medicine suggested that errors are most likely to be prevented when a variety of approaches are used at the same time [4].

The Veterans Affairs Northwest Network (VISN20) is using many approaches to reduce medication errors, including the introduction of automated systems to the point of care. We describe here the use of our clinical event monitor developed by VISN20 to prevent and detect medication errors.

Setting

This project is being conducted at the Veterans Affairs Northwest Network, the collection of eight VA medical centers in the Pacific Northwest. Initial implementation of the clinical event monitor is at the largest of those medical centers: VA Puget Sound Health Care System in Seattle and Tacoma, Washington. VA Puget Sound consists of 2 medical centers with 512,500 outpatient visits and 10,196 discharges annually. The combined medical centers have 536 beds of which 315 are for acute care. The Seattle Division is a major teaching hospital of the University of Washington, training 485 residents and many medical students each year.

CPRS and Vista

In 1997, we began installing the Veterans Affairs Computerized Patient Record System (CPRS) in wards and clinics of VA Puget Sound. In 1998 we began using CPRS for order entry on our busiest inpatient wards and critical care units [5]. Since October, 1999, CPRS has been used to enter all orders (except for cancer chemotherapeutic agents and total parenteral nutrition orders) in all inpatient units (except for the Bone Marrow Transplant Unit). In the outpatient setting orders can still be entered on paper. Of the up to 12,000 orders entered on VA Puget Sound wards and clinics each weekday, roughly two thirds are entered into CPRS directly by practitioners.

CPRS is part of Vista, an integrated system of applications that share a common database [6]. All VA medical centers use Vista, which includes pharmacy, laboratory, admission/discharge/transfer, and other departmental systems. When practitioners enter a medication order in CPRS, it is communicated both to the ward or clinic and to the pharmacy. Pharmacists then 'finish' the order; this separate step transforms the order into a form that can be filled by the outpatient, inpatient (unit dose), or IV pharmacy packages. If practitioners enter a medication order on paper in the outpatient setting or in the Bone Marrow Transplant Unit, pharmacists enter and finish the order in a single step.

SYSTEM

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This report covers the use of the clinical event monitor in one of many domains in which it can be applied.

Clinical event monitor description

Clinical event monitors are computing systems that 'scan' electronic messages containing new clinical and administrative information sent between clinical computing systems (or from within a single system), and notify clinicians when patterns are detected that warrant attention, by generating alerts, reminders, or by some other mechanism. They have been applied to many domains, including alerting clinicians when worrisome trends are noted in laboratory results, when new microbiologic results are available, and for other purposes [7,8]. We have developed a clinical event monitor for use with CPRS and other data sources that we have described in an earlier report [9].

The clinical event monitor is an event-oriented application. It takes advantage of features available within Vista to trigger events during order processing and admit, discharge, and transfer (ADT) movements. Vista includes a sophisticated event handling system that forms the backbone of communications between CPRS and the other departmental applications. Information about the events is available in the form of HL7 messages created by communicating applications. The event monitor "subscribes" to the events within Vista that are most closely linked to the clinical activities to be monitored. Currently we monitor clinical events of the following types: a hospital admission, discharge or transfer; an inpatient or outpatient medication order entered by a practitioner; and, an inpatient or outpatient medication order verified by a pharmacist. Whenever one of these events occurs, a program is activated which inspects the HL7 message describing the current event. If the event meets the criteria for monitoring, the server contacts the clinical event monitor over a TCP/IP socket and sends it a description of the event in an augmented copy of the HL7 message. Vista software does all of this "silently," that is, without visibly intruding on users' activities.

In summary, software within Vista taps into the constant chatter between Vista applications regarding the clinical events taking place, identifies those events that most closely correspond to those clinical events of interest, and translates them into a steady stream of HL7 messages sent to the clinical event monitor.

The clinical event monitor system architecture is based on Microsoft's Distributed Internet Architecture (DNA). It consists of four Windows NT services that communicate by passing data across an intranet as messages through message queues. These four services are: (a) the message queue service; (b) the message processing service; (c) the rule service; and (d) the scheduling service. The *message queue service* saves incoming HL7 messages (currently received from Vista applications) to a message queue for subsequent processing. *The message processing service's* primary function is: (a) to determine which rules, if any, are associated with the incoming HL7 message; and (b) for each rule identified, to output a copy of the HL7 message received together with a rule identifier prefix, as a single message, to the rule service's input message queue. The *rule service* then executes the business logic associated with the rule identifier. When medication orders are entered into CPRS directly by practitioners or by pharmacists, HL7 messages are sent to the event monitor, and one or more of the collection of rules associated with medication orders is invoked. If a business rule concludes 'TRUE,' so that some action is to be taken, the business logic specifies who is notified and by what communication mechanism. Communication mechanisms include electronic notifications sent to a specific user through CPRS (view alerts), email, digital page, and printing to a departmental printer.

Business rules are programmed to conform to Microsoft's Component Object Model (COM). This requirement provides both system scalability and system extensibility. COM services (Microsoft Transaction Server in Windows NT 4) provide the required system scalability by allowing for the rapid reuse of all rule objects. By requiring that business rules be programmed as COM objects, the rule service can run named subprograms without any prior knowledge about them. The initial input to any business rule is limited to the information contained in the HL7 message that activated the rule. Business rules execute remote procedures to retrieve additonal data by calling a single method on a common COM interface. As a consequence, a business rule can access data from any COM object that implements

Table 1. Event monitor rules for the prevention and detection of medication errors.

Rule description	Relevant medications
Notify Adverse Drug Event Coordinator when specific medications are ordered that might indicate an adverse medication event	Digibind soln IV, flumazenil inj, naloxone, sodium polystyrene sulfonate susp.
When a new order for amiodarone occurs for a patient also taking warfarin, notify the pharmacist if the most recent INR is > 3.0. Check for INR result weekly for 4 weeks.	Amiodarone, warfarin
When a medication order is verified by the pharmacist, check if the dosage is below a recommended maximum dosage limit.	(35 medications)
When selected drugs are ordered check the most recent serum level of an associated lab test result. If the result value is >= the high end of the normal range print a warning on the appropriate pharmacy printer.	digoxin, aminophylline, theophylline, lithium, warfarin, phenytoin, others
When a new order for eptifibatide (Integrilin) occurs, send the ordering provider a view alert reminding them of a drug interaction with heparin.	eptifibatide, heparin
When a new order for rosiglitazone occurs, check SGPT result every 2 months during the first year. If no result is found; or an abnormally high result is found, send a view alert to the monitoring authority.	rosiglitazone
If a drug is prescribed that interacts with a medication that was discontinued within a specified time in the past, notify the monitoring authority.	methotrexate, trimethoprim/sulfa
Notify endocrine fellow or resident that patient is taking cosyntropin.	cosyntropin

this data interface. Data is returned in Extensible Markup Language (XML) format. Business rules schedule other business rules by placing an HL7 message in the event monitor's application database to be retrieved by *the scheduling service* at a scheduled future date.

Clinical event monitor statistics

The clinical event monitor first entered production use on August 1, 1999. At the time of this writing there are ten rule categories in use in the production clinical event monitor at VA Puget Sound. Of these, eight pertain to the domain of the prevention and detection of medication errors. These rules, and the medications covered by each rule are listed in Table 1. An example rule is dose limit checking. When selected medications are verified by a pharmacist, a "dosage limit" rule parses the order to identify both the medication and dosage. A table stored in the event monitor database provides a maximum dosage for the specifc medication. If the actual dosage is above the maximum dosage, specific pharmacists are notified by email. At the time of this writing, this rule covers 35 medications.

Each outpatient and inpatient medication order, whether entered directly by the practitioner or written on paper and entered by the pharmacist, results in a message sent to the clinical event monitor. Each order event, therefore, is available for scrutiny. Table 2 shows the average number and type of events recorded by the clinical event monitor on weekdays during the month of June, 2000. Each event sent an HL7 message to the event monitor for subsequent processing. HL7 Messages for verified orders exceed messages for electronically signed orders as a substantial portion of outpatient medication orders are written on paper.

Table 2. Number and type of events generating HL7 messages received by the clinical event monitor each day. (Average of 22 weekdays, June 2000).

Event type	Number
ADT Admission	35
ADT Transfer	19
ADT Discharge	29
Medication order, signed	1919
Medication order, verified by pharmacist	2800

Table 3 reports the number of times that each rule described in Table 1 concludes true or false during the month of June, 2000. A rule outcome of true indicates that the rule took some action, for example, sent email, a view alert, or printed to the departmental pharmacy printer. The elapsed time between the signing of the medication order and the

Table 3. Number of medication-related rules and rule conclusion during the month of June, 2000.

Rule	FALSE	TRUE
Notify ADE Coordinator	115	75

Amiodarone-warfarin,check INR	90	10
Dose limit checking	694	0
Drug serum level monitoring	1053	20
Integrilin-heparin reminder	NA	10
Rosiglitazone check SGPT	15	6
Interaction with D/Cd drug	231	0
Cosyntropin alert	NA	5

completion of the rule varies with Vista system load, but is < 5 seconds. Part of this delay is due to order processing tasks within CPRS.

DISCUSSION

Medication errors can be prevented and detected by automated systems in many ways. In CPRS, for example, order checks applied in real-time give feedback to the ordering clinician during the ordering process, and before the order is submitted to the pharmacy. Clinical reminders generate messages that can be viewed when a patient's record is called up. Notifications are sent to clinicians through displays available within CPRS, and through terminal emulation screens outside of CPRS. However, given the breadth and complexity of medicine, it is not surprising that these features do not cover all possible types of medication errors. For example, at present orders entered into CPRS are not automatically checked for dose limit errors. Some VA medical centers check certain high-risk medication orders for dose limit errors in other ways using the pharmacy package. At VA Puget Sound, for example, cancer chemotherapeutic agents administered intravenously are checked for dose limit violations as the pharmacist enters the order into the IV package.

The clinical event monitor is designed for areas that are not comprehensively covered by existing order checks, reminders, or notifications. Event monitor rules differ from reminders in that they are designed to be 'event driven' and can take action within seconds of a new order, new result, or ADT movement. Event monitor rules can contact clinicians through a variety of routes independent of CPRS or computer screens if appropriate. A type of error not checked by CPRS is the omission of appropriate future laboratory monitoring for certain medications. The scheduled monitoring of such a drug-lab interaction is complex and entails the use of a two-stage rule. When a medication order is received the initial rule schedules a second rule that runs at a specified future date. The second stage rule then determines if the expected laboratory monitoring result is available or if the laboratory result exceeds a prespecified maximum value.

The event monitor uses a variety of routes to contact clinicians if the rule concludes TRUE. Ideally, it would be able to respond during the ordering session if it detected an error, just as CPRS order checks do at present. We do not yet use the order checking application programming interface to create a pop-up window to notify the ordering clinician. At present event monitor performance is fast enough to run relevant order check rules within seconds. However, we have not designed the event monitor to interact with the clinician during the ordering session. As our library of rules grows, it may experience more substantial delays when processing rules, especially during peak ordering periods. An important lesson learned to date is that the event monitor's system design and hardware can receive and process the volume of incoming medication orders generated in our medical center without imposing a significant performance impact on CPRS.

Issues

We have learned, as others have, that creating helpful, credible rules is an iterative process [10]. The initial rule logic may appear sound, but over time problems with the business logic are identified. Because each rule is an independent component, such problems can be readily corrected. An example of this iterative process involves the rule that searches for dose limits of medications such as hydromorphone. Initially the dose parsed from the HL7 message was compared against the table containing dose limits, but when this rule was first used it 'fired' when orders were entered for hydromorphone drips were received, in which large amounts of the drug are mixed in a liter bag and infused slowly. Since the drug was infused slowly, it did not represent a dose limit error. We subsequently modified the rule to determine if the order was for a drug infusion, and if so, the order was ignored.

Use of the clinical event monitor by organizational committees

The Medication Misadventure Review Group is a multidisciplinary team at VA Puget Sound charged to prevent potential and actual medication errors. This group generates ideas for new rules based on adverse medication reports that it receives. One of the authors (CTH) is the Adverse Drug Event coordinator who is responsible for studying adverse medication events, and is heavily involved in review of candidate rules and the creation of new rules. The Pharmacy and Therapeutics Committee proposes ideas for new rules. Lastly, when isolated reports of problems are received, new rules can be written to prevent future occurrences. Currently our library of rules is much smaller than our goal.

Clinical impact

The greatest clinical impact of the event monitor in the domain of medication error prevention and detection has been to identify instances of probable adverse medication events that had not been identified by other means (ADE notification rule). For example, over a one month period the event monitor allowed identification of 4 cases in which sodium polystyrene sulfonate was prescribed to patients for hyperkalemia as a result of the concurrent use of 2 medications that can independently elevate serum potassium. Only one of these 4 cases had been reported using a voluntary reporting system. Others have had similar success in using automated systems to track adverse drug events [11]. We have yet not detected dose limit violations that were not identified by other mechanisms. This is not surprising; such undetected errors are not common. However the event monitor serves as an additional layer of protection for such potentially catastrophic errors.

Future plans

One of the design objectives is for the clinical event monitor to be 'portable' so that it can be used in a variety of health care locations, and use multiple data sources other than Vista. We are planning deployment of the event monitor in a second VISN20 site in the near future. We also realize that there is tremendous potential to use the clinical event monitor to cover a wide variety of potential medication errors, and to rapidly detect errors that have occurred [11]. We are regularly adding the library of rules within the event monitor database.

CONCLUSIONS

We have found the clinical event monitor to be a valuable tool for clinicians and quality management groups charged with improving medication safety. Our current design allows us to rapidly scrutinize every medication order generated in the medical center in which it is currently used, without impairing performance of our clinical computing systems. This general tool also serves an important role in enhancing the safety of medication use.

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REFERENCES

[1] Leape LL. Error in medicine. JAMA 1994;272:1851-1857.

[2] Bates DW, Cullen DJ, Laird N et al Incidence of adverse drug events and potential adverse drug events. Implications for prevention. JAMA 1995;274:29-34.

[3] Bates DW, Leape LL, Cullen DJ, et al. Effect of computerized physician order entry and a team intervention on prevention of serious medication errors. JAMA 1998;280:1311-1316.

[4] Committee on Quality of Health Care in America, Institute of Medicine. Kohn L, Corrigan J, Donaldson M, eds. To Err Is Human. Building a Safer Health System. Washington, D.C.: National Academy Press, 1999.

[5] Payne TH. The transition to automated practitioner order entry in a teaching hospital: The VA Puget Sound experience. Proc AMIA Symp. 1999;589-93.

[6] Kolodner RM, editor. Computerizing Large Integrated Health Networks. The VA Success. New York: Springer-Verlag, 1997.

[7] Hripcsak G, Clayton PD, Jenders RA, et al. Design of a clinical event monitor. Computers and Biomedical Research. 1996;29:194-221.

[8] Hripcsak G, Knirsch CA, Jain NL, Pablos-Mendez A. Automated tuberculosis detection. JAMIA 1997;4:376-381.

[9] Payne TH. Savarino J. Development of a clinical event monitor for use with the Veterans Affairs Computerized Patient Record System and other data sources. Proc AMIA Symp. 1998;145-149.

[10] McDonald CJ, Overhage JM: Guidelines you can follow and trust. An ideal and an example. JAMA 1994;271:872-873.

[11] Classen DC, Pestotnik SL, Evans RS, et al. Computerized surveillance of adverse drug events in hospital patients. JAMA 1991;266:2847-2841.